Executive Summary
Bomber Industrial Capabilities Study

Prepared for
The Undersecretary of Defense
Acquisition and Technology

June 1995

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Study Requirements

In response to the requirements of the *FY95 Authorization and Appropriations Acts*, TASC, a leader in industrial analysis for military systems, performed a study of industry's current and future capability to design, develop, and produce bomber aircraft. The study is the result of concern on the part of both the Congress and the Department of Defense that the coming end of B-2 production could jeopardize the nation's ability to produce bombers in the future.

TASC's approach to this requirement involved three tasks. The first was to identify the core industrial capabilities associated with heavy bombers and determine whether these capabilities are dependent on continued B-2 production. This task also assessed the likelihood that essential bomber industrial capabilities would be retained through other military and commercial aircraft programs. The two remaining tasks examined the aircraft industry's ability to restart the B-2 or initiate a new bomber program if required in the future.

The key to our findings in each of these areas is the word "capabilities", which we define to include the skills, processes, facilities, technologies, and other resources that enable industry to meet the particular requirements of different aircraft. Like all other complex systems, the B-2 possesses subsystems that have been designed to meet specific mission requirements and that are not found elsewhere. However, from an industrial base perspective, it is not these specific design features that are important -- it is the underlying industrial capabilities that created them and could create similar solutions again that are the critical issues under invetigation in this study.

Study Requirements

"... Determine those core bomber industrial capabilities that are needed to maintain the ability to design, develop, and produce bomber aircraft in the near-term and in the long-term and that ... would take extended periods of time or substantial expense to regenerate, ... and are in imminent danger of being lost"

(FY95 Authorization Act, Section 133(b)(1))

APPROACH

1. Identify B-2 core industrial capabilities

   What capabilities matter?

   Are they available in the broad industrial base?

   Will they continue to be in the future?

2. Assess options, costs, and time of potential B-2 restart
3. Assess impact on capability to design and produce a potential future bomber

Comprehensive Review of Aircraft Capabilities

TASC applied a variety of methods to identify core industrial capabilities required by the B-2 and to assess the aircraft industry's ability to produce a bomber in the future.

First, the study drew on the expertise of approximately 200 senior representatives of all aircraft prime contractors, including Northrop Grumman, the B-2 prime, and major B-2 subcontractors. Each site visited involved 1-2 days of structured discussions on industrial capabilities in each area of the team's aircraft Work Breakdown Structure (WBS). Discussion topics included the complexity of manufacturing processes for each element, the identity and viability of current sources, and unique aspects of B-2 as compared to other aircraft. Additional information was gathered through written questionnaires to each company, discussions with personnel at the B-2 SPO, a review of the many analyses that have been performed on different facets of the B-2, and a review of the pertinent technical literature. Visits were also made to the JAST program and the F-22 System Program Office (SPO) to better understand technology developments that could contribute to a future bomber.

Following the data collection phase, the team compared B-2 design solutions to those of other aircraft to identify significant differences in the capabilities required for design and production. Experts worked with the team to assess the impact of differences in scale, maturity, and complexity between the B-2 and other aircraft.

This technical effort was complemented by an economic analysis of the aircraft industry and financial analyses of individual contractors who were responsible for producing important parts of the B-2.

Other analytic methods were used in the investigation of restart. One involved case studies of the restart of the C-5 and B-1, as well as industry's ability to accommodate interruptions in production for the P-3. These case studies yielded "lessons learned" that can reduce the cost and time of restarting the B-2, if required. The case studies entailed visits to facilities where restart occurred and discussions with corporate executives and other individuals who were personally involved in restart activities.

Finally, independent cost, schedule, and risk estimates for restart options and for development and production of a new bomber were developed. The estimates were consistent with those developed previously by Northrop Grumman, the Air Force, the OSD CAIG, and IDA. While the outside estimates assumed that a decision to resume or restart B-2 production would be made in the near-term (i.e., 1997), TASC's estimates assumed a restart decision in the post-2000 time frame.

All project activities were guided by a TASC-sponsored Senior Advisory Panel of distinguished individuals knowledgeable in bomber programs and the U.S. aircraft industry. Panel members are listed below.

Comprehensive Review of Aircraft Capabilities

Site Visits Completed:

B-2 SPO	Dayton, OH
Northrop	Pico Rivera, CA
Northrop	Palmdale, CA
Rockwell	Palmdale, CA
Lockheed Adv Dev	Palmdale, CA
Boeing	Seattle, WA
McDonnell-Douglas	St. Louis, MO
	Long Beach, CA
Lockheed	Marietta, GA
Northrop/Vought	Grand Prairie, TX
AF Cost Library	Dayton, OH
Hughes	El Segundo, CA
Loral	Owego, NY
General Electric	Evendale, OH
F-22 SPO	Dayton, OH
JAST Program	Washington, D.C.

Types of Analysis:

- Survey of aircraft industry capabilities
- Engineering comparisons between B-2 and other military aircraft
- Analysis of aircraft industry business trends
- Cost/schedule/risk analysis of B-2 restart and new bomber program options
- Case studies of past military aircraft program restarts

TASC Senior Review Group

Dr. G. Ronald Fox	LTGEN (Ret) Bill Thurman
Dr. David Lee	Mr. John Stewart
LTGEN (Ret) George Sylvester	Mr. Gordon England

Dr. Jacques Gansler

B-2 Draws From Broad Industry Capabilities

Some people assume that there is a distinct “bomber industry” whose capabilities are applied chiefly (or exclusively) to bomber aircraft. And, indeed, there is a specific team of firms that is developing and producing a particular bomber at a particular time. However, the team is dissolved when the program ends, and a new and different industrial team will be created to support the next generation of bombers. The intermittent nature of bomber programs could not support a dedicated base, even if one were desired.

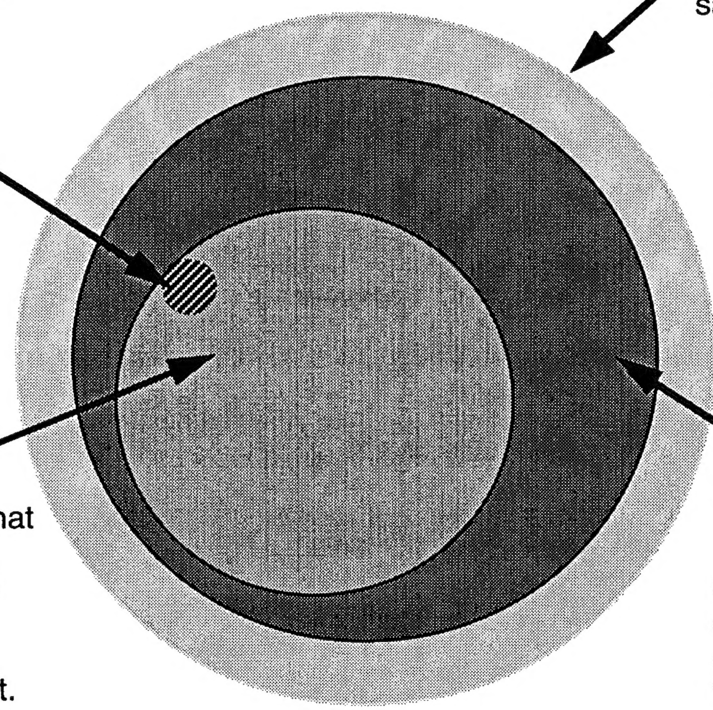
In fact, there is no distinct “bomber industrial base”. This chart graphically depicts how the B-2, with its unique features, fits into the broader array of industrial capabilities. In a counter clockwise direction, the companies supporting the B-2 program are a subset of the larger military aircraft industrial base. Many firms supporting military aircraft programs also support the larger aircraft industrial base that is involved with both military and commercial fixed and rotary wing aircraft. Lastly, many of these firms also support the highest level of industrial capability shown on the chart, the aerospace industry.

Most of the firms engaged in some aspect of aircraft production deal with complex products that require some of the highest levels of quality, reliability, and performance within the manufacturing infrastructure. Consequently, firms representing the aerospace sector typically require a highly skilled and technologically competent work force and are pioneers in many technologies.

B-2 Draws From Broad Industry Capabilities

Unique B-2 Features
Those skills, materials, processes, equipment and facilities required only by the B-2.

Aerospace Industry
A leading national industry in sales, employment, and innovation. The industry which supports bombers, other aircraft, missiles, and space systems.



Military Aircraft

That part of the aircraft industry that collectively possesses the skills, materials, processes, equipment and facilities required to design, develop and produce heavy bomber and other military aircraft.

Aircraft (Military & Civil) Industry

Supports design and production of commercial and military aircraft -- from helicopters to transports, fighters... and bombers.

B-2 Industrial Capabilities are Not Unique

TASC prepared and applied a military aircraft work breakdown structure (WBS) as a central mechanism for data collection and analysis. At all contractor locations visited, discussions were held about elements of the WBS that might dictate unique industrial capabilities for B-2. The discussions and analysis led us directly to the first major conclusion of the study: "the capabilities required to produce the B-2 today are common to other military aircraft. B-2 industrial capabilities are not unique."

Universally, the team found that the B-2 has many unique features, but that the industrial capabilities needed to produce these features are established in the aircraft industry. These capabilities could continue to support B-2 or future bombers, if needed.

While the production of a particular component or subsystem might be terminated when B-2 contract activity ends, industrial capabilities will still be applied to other aircraft. Similarly, the termination of B-2 work will lead to the diversion of facilities and/or reallocation of labor and equipment to other aircraft programs. If a new bomber or B-2 restart is required in the future, essential capabilities would still be available, subject to the assumptions that: (1) critical skills and capabilities are maintained and advanced through other military aircraft programs and technology efforts such as the F-22 and JAST; and (2) a robust commercial aircraft industry continues to sustain a healthy supplier base. These assumptions are discussed in more detail later in this report.

B-2 Industrial Capabilities Are Not Unique

Military Aircraft Work Breakdown Structure

Air Vehicle

Airframe
- Fuselage
- Wing
- Empennage*
- Landing Gear

Software

Systems Engineering/ Integration

Weapons Carriage**
- Bombs
- Cruise Missiles
- Other Missiles

Propulsion
- Engine
- Exhaust System
- Engine Controls

Subsystems
- Auxiliary Power Unit
- Wheels, Tires & Brakes
- Simulation & Training Systems
- Heat Exchangers
- Electrical Generator & Power Distrib
- Environmental Control System
- Oxygen Generation & Distribution
- Fuel Management System
- Weapons Carriage System
- Hydraulic System
- Flight Control

Electronics
- Displays & Instrumentation
- Electronic Warfare
- Navigation
- Communications
- Weapons Control/Targeting
- Sensors
- Misc./Multipurpose

* B-2 has no empennage -- other surfaces perform functions

** Stealth requires internal carriage: other bombers have both internal and external carriage

The consensus of about 200+ industry and government executives representing fifteen organizations: The capabilities required to produce the B-2 are common to other military aircraft.

Primes Can Produce All Types of Military Aircraft

Similarities in capabilities needed to produce different aircraft can be illustrated by contract awards to aircraft prime contractors. Traditionally, the aircraft industry has not been rigidly segmented into bomber, fighter, and transport producers. Given the size, dollar value, duration, and infrequency of major contracts, primes tend to compete irrespective of their most recent experience. As history has shown, companies produce aircraft, not just a single type of aircraft. The flexibility demonstrated by aircraft primes in the past may be even more pronounced as the industry consolidates and the experience base of the new companies expands.

The aircraft portion of the aerospace industry now consists of four companies having sufficient management, engineering, and manufacturing capabilities to lead a new bomber production team: Boeing, Lockheed Martin, McDonnell Douglas, and Northrop Grumman. All four are large, with Northrop Grumman being the smallest with 1994 sales of over $6 billion. Additionally, Rockwell remains viable as a potential team leader. These companies form different teams for different programs. For example, Boeing is a subcontractor to Northrop Grumman on B-2 and to Lockheed Martin on F-22, while Northrop Grumman and Lockheed Martin both are suppliers to Boeing for several commercial airplanes.

"Primes" Can Produce All Types of Military Aircraft

- **In the past 45 years, bomber production has shifted from prime to prime:**
  - No firm or team has produced heavy bombers for more than 15 years running
  - No firm or team has won consecutive heavy bomber production contract awards
  - No bomber contract has been awarded to a firm with another fighter, bomber, or military transport in production
- **No heavy bombers were produced between 1962 and 1982 (excluding prototypes). No capabilities were lost during the gap**
- **Over the last 30 years, General Dynamics changed from bomber to fighter, Northrop shifted from fighter to bomber, and Lockheed has produced both fighters and transports**

Aircraft primes from time to time shift between aircraft of differing scale and complexity

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B-2 Component Suppliers Also Supply Other Programs

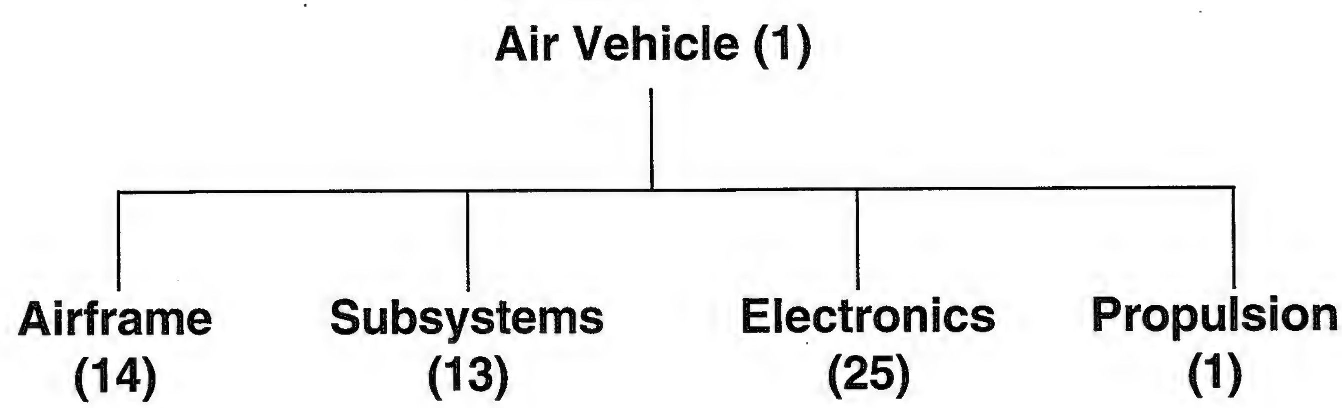
Flexibility within the aircraft industry is also demonstrated by suppliers. Prime contractors are supplied by a broad array of aerospace and non-aerospace firms for aircraft development and production. This supplier base supports not only the aircraft primes, but may also serve helicopter, business aircraft and light aircraft producers, whose total business is a significant portion of the total aerospace market.

Northrop Grumman has identified 54 key suppliers for the B-2, based on shares of the B-2 cost. All of these suppliers do work for other aircraft (and even non-aircraft) programs and will continue to work in their current lines of business after B-2 production ends. The study team could identify no key sources that would be lost or otherwise endangered by the end of the B-2 program.

Although the study schedule did not permit the team to separately analyze the viability of the thousands of suppliers who supported B-2 during its peak years, executives from Northrop Grumman and its major subcontractors (Boeing, Vought, Hughes and Loral) identified only a single instance (a small dedicated materials supplier) where a supplier was put out of business or left aerospace production when its B-2 orders ended. Once again, our conclusion is that key capabilities will not be permanently lost when the B-2 program ends.

However, we would again stress the critical role to be played by: (1) other military aircraft efforts, such as the F-22 and JAST, in sustaining the technology and industrial capabilities required for high performance military aircraft, and; (2) the commercial aircraft industry in sustaining a healthy supplier base.

B-2 Component Suppliers Also Supply Other Programs



All 54 key B-2 suppliers also supply other aircraft and/or non-aircraft programs.

( ) = Number of suppliers identified by Northrop Grumman as providing more than 0.1% of the value of the aircraft (or 0.01% for electronics).

Unique Features of B-2

While the study team concluded that B-2 **industrial capabilities** are not unique, it is nevertheless true that the B-2 is a complex aircraft that is unlike any other. The industrial capabilities have developed and produced a truly unique airplane -- not just in the sense that every airplane is unique, but also in its combination of bomber mission capabilities, configuration, and stealthiness. The companies responsible for B-2 have employed many special materials and innovative processes to ensure that the aircraft meets its mission requirements. Some of the important features that differentiate B-2 from other aircraft are shown on this chart.

As previously stated, the B-2's demanding performance requirements have dictated very specific (and frequently challenging) design solutions. The B-2 team's achievements were precedent-setting in major respects, but from an industrial viewpoint, it is important to note that the ***basic industrial capabilities*** to produce the B-2 were generally present in the aircraft industry at the start of B-2 production a decade ago. Although many of these "revolutionary" features may not have been supported by a mature base of industrial capabilities when they were new, technologies that were first applied to B-2 have since found use in other programs, thereby expanding capabilities to a wider network of sources.

Stealth requirements are the source of the most demanding of the B-2's unique features. Stealth has its strongest effect on airframe elements of the work breakdown structure (WBS), including a unique integrated wing design with very low observables (VLO) shaping, extensive use of low observables (LO) materials, and unprecedented outer moldline tolerances. These features have presented major manufacturing challenges to B-2 contractors. In the propulsion system, stealth considerations led to the requirement to mask inlet and exhaust systems, as well as to cool the exhaust, which required a unique and extremely complex exhaust system. Such innovative design features in turn dictated a unique engine fan design. The electronics systems are generally similar to systems in other aircraft but, again, stealth-driven requirements for embedded antennas and for integration of the low probability of intercept (LPI) radar and its radome led to unique B-2 design solutions.

The next five charts address issues within each of the major WBS elements:

- The air vehicle **(systems integration)**
- Airframe (**large composites** and **stealth**)
- **Subsystems**
- **Electronics.**

Unique Features of B-2

Specific Features of B-2

Air Vehicle

Complexity
Systems Integration

Airframe

Large composites
Large titanium forgings, castings, extrusions & superplastic formed parts
Tight tolerances on large composites & titanium
Integrated wing design with VLO shaping

LO materials
Outer moldline tolerances
- Dimensions
- Smoothness

Edge structures
Treated honeycomb
LO/hardened windshield

Subsystems

Flight control integration
Fuel management
Rapid actuators
Weapons integration
Hydraulics
Embedded air data system

Software

Code
Integration

Propulsion

Engine fan
Exhaust system

Electronics

Avionics integration
Embedded antennas
LPI radar/radome integration
Waveguides
Defense management system

When first developed, many features required development as unique capabilities but these capabilities are now available within industry

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System Integration

Experience and skills in systems management and integration are fundamental to the success of any large aircraft program, and this was particularly true for B-2. The "revolutionary" nature of the B-2 (coupled with its shroud of secrecy) caused its transition from development to production to be among the most difficult faced by any weapons system. The management team -- business as well as technical -- that ultimately succeeded was one that had substantial depth of experience in the management of large, complex systems. Many members of this team were drawn from other large, complex aerospace programs, including the space shuttle and the B-1 bomber.

The elements shown here are illustrative of the management requirements associated with the B-2, but by no means do they convey their magnitude. The integration of a highly complex program demands both specialized skills and hands-on experience, and there is concern within the industry that the number of new program starts is declining so sharply that the opportunity for gaining experience -- especially on multiple programs -- may erode in the future. This problem could be exacerbated by the replacement of experienced but aging workers by a "new generation" of inexperienced personnel. Although this issue has been important to the B-2 and will have a major impact on any future bomber program, its impact is aerospace-wide and only negligibly affected by the decision to limit the B-2 program to 21 aircraft. The continuation of B-2 production would not exercise these skills as did the original transition to production. Currently, within the Defense budget, there are a number of ongoing programs (see below) that, if maintained at their projected levels, would be sufficiently complex to maintain the requisite system integration skills needed for a bomber restart and, more importantly, for development of a new bomber program.

System Integration

- Requires experienced, skilled engineering managers to formulate programs

Business

- Selected and managed 4,000 suppliers nationwide
- Established major suppliers' paperless operations

Technical

- Blended wing/body aerodynamics with low observable large composite airframe structure
- 132 on-board computers; 1.8 million lines of code

- Traditionally, skilled systems engineers have migrated from existing programs to new programs
  - B-2 program used shuttle, B-1, and others as sources of skilled managers
- In 1990's, there will be fewer military aircraft programs to develop these skills (B-2, F-22, V-22, F-18 and C-17)
- Software development and integration is a major and continuously growing problem across the military aircraft industry

B-2 "build to print" restart can be supported from available engineering pool and would contribute negligibly to expanding the engineering talent pool

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Stealth

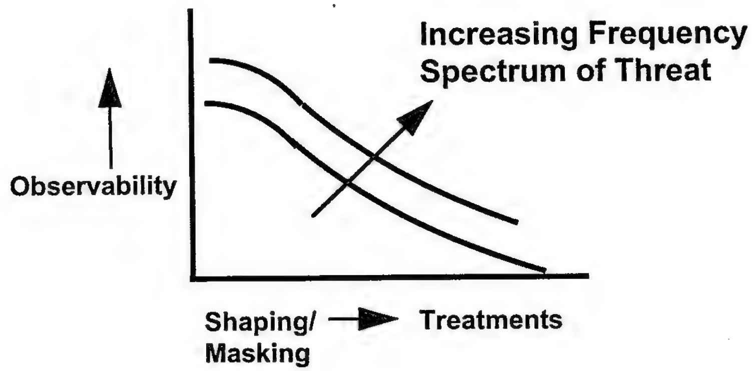
Stealth technologies required for the production of the B-2 are similar to those being used on the F-22. Most stealth capabilities are achieved through design operations which shape the vehicle to reduce/eliminate the return of energy to the radiating source and mask the major sources of return and vehicle radiation, such as the engine and canopy, by burying them within the airframe, and by local treatments. The achievement of these stealth characteristics is a basic tenet of low observable (LO) design, a capability which now resides in important segments of the industry and would be available for either a new bomber or a B-2 restart.

Stealth materials are employed to absorb energy in selected areas, and to collect and control energy in other areas of the structure. Non-metallic cores are used in some portions of stealth systems and are treated to absorb particular energy inputs. One particularly important material is honeycomb. Northrop Grumman acquired a supplier of this material to ensure a secure source for B-2. However, honeycomb is also used on other vehicles and is available from other sources, including DoD and commercial suppliers.

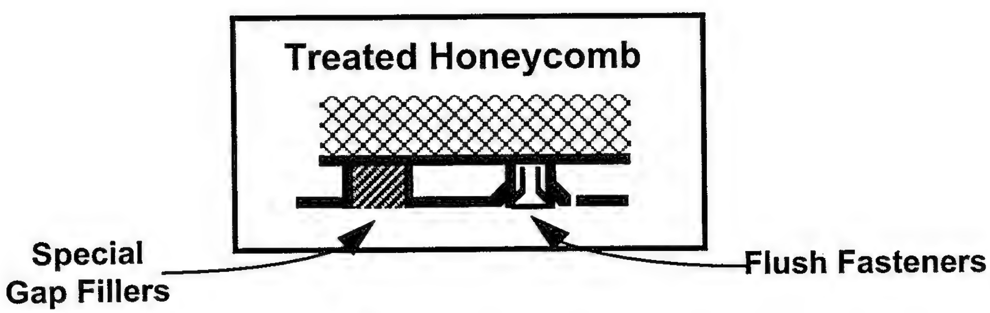
Both bomber and fighter/attack aircraft designs must deal with masking the infrared energy emitted from engine exhaust. The treatment technology would be available from industry sources outside the B-2 team, if required.

In summary, unique stealth features associated with the B-2 would be available to support the restart of B-2 production or the development of a new large bomber. Companies currently involved in the development of LO systems could reconstitute their capability to support either option in a reasonable timeframe. Continued R&D in the area by both DoD and industry raises the additional possibility that improved LO materials could be available for these systems, improving both effectiveness and cost.

Stealth



- Shaping and masking are key to all stealthy aircraft
- Treatment solutions for large and small aircraft are similar
- Different materials perform the same functions
- All military aircraft producers have participated in stealth programs



Stealth capabilities for future bombers will be retained and advanced through B-2 Program Depot Maintenance, F-22, JAST RDT&E and production, and other programs

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Structures

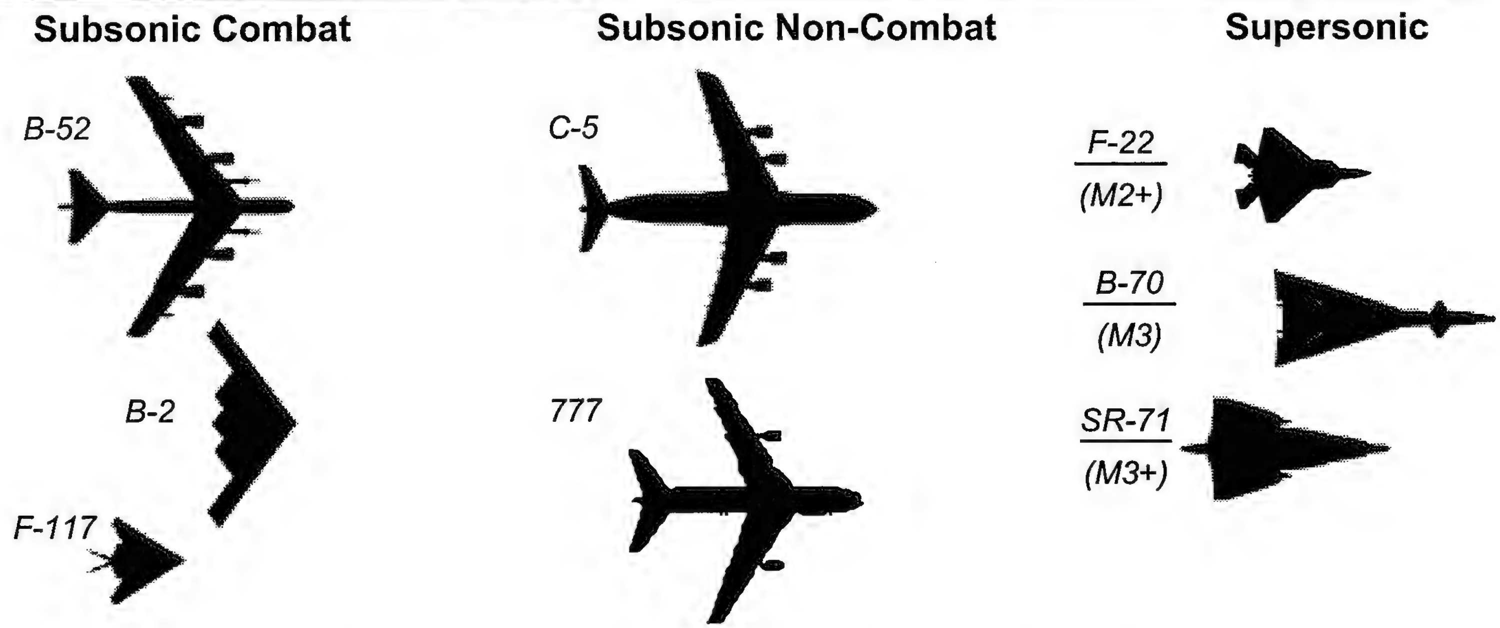
The basic design and analysis tools, materials, and processes for aircraft structures, are common across the industry. The major departures from industry norms for structure fabrication and assembly for the B-2 were caused by stealth requirements.

Assembly for any stealth aircraft is an extremely exacting and time consuming process, but the issues are the same for both bomber and attack/fighter systems. For the B-2, these requirements created a number of manufacturing challenges:

- Designed and built from the outside-in, to outer mold line tolerances for unprecedented shaping and smoothness control
- Very large composite airframe structures-specially dipped honeycomb core
- Special shaping and coatings for leading edges
- Establishing smooth, flush, and non-wavy external surfaces for low-observability, special taping, caulking, and smoothing operations
- An order of magnitude of greater precision for structural tolerances compared to commercial aircraft
- Use of adaptive drilling to sense the changes in materials (composites-titanium) when drilling through layers of the structure for fastener holes
- Three weeks to mate major sections during assembly using theodolite alignment (versus eight hours for the B-1)
- Embedded antennas
- Specially-designed LO tail pipes
- Precise control of paint thickness

Thus, while it is true that no unique industrial base ***capabilities*** are required, it also is true that the B-2 program advanced the state-of-the-art in many processes.

Structures



- Analytic methods and tools (e.g., finite element analysis, etc.), materials, and processes for aircraft structures are common across industry
- Specific configurations are driven by design solutions of particular mission and aerodynamic requirements
- Structures for high performance military aircraft are more complex than for commercial aircraft. Internal weapons carriage causes special structural problems for stealth aircraft

Structural arrangement solutions are similar for different types of military aircraft (including flying wing) and require no unique industrial base capabilities

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Composite Structures

Composite materials provide the performance and manufacturing flexibility necessary to achieve the highly efficient structures and surface-controlled shaping required for stealth.

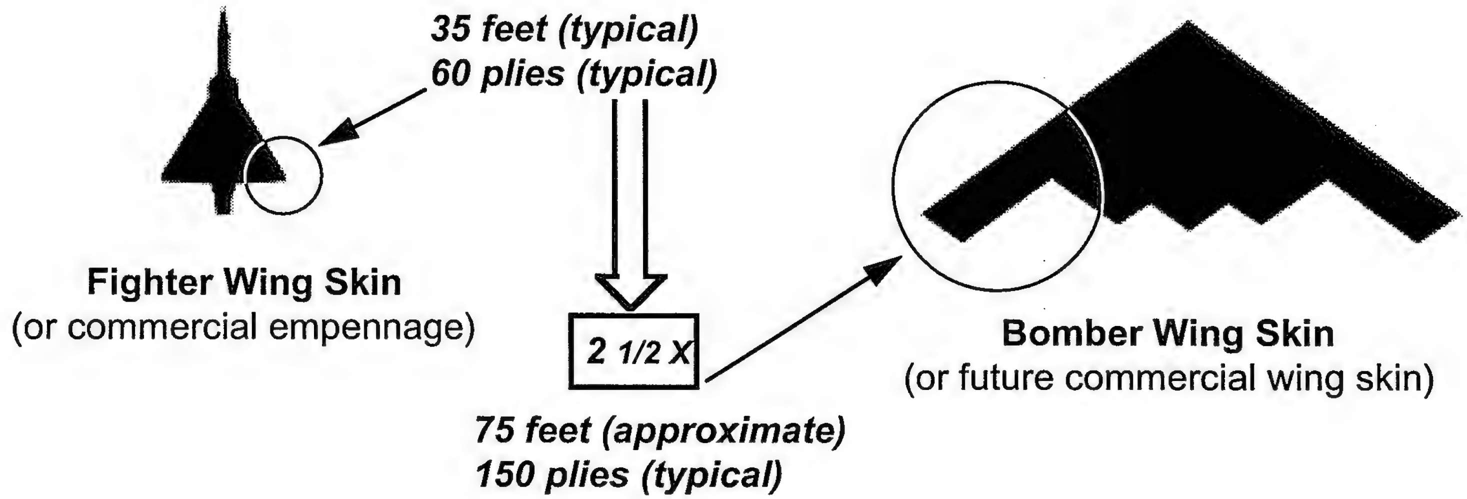
B-2 contains the largest airframe composite structures ever produced. Its wing box is about 2 1/2 times the size of fighter wings or commercial aircraft empennages in both planform and thickness. Despite their size, large composite structures for B-2 were fabricated using conventional materials processing (tape laying, hand lay-up and autoclave curing) and subsequent inspection (x-ray and through transmission ultrasonics). These techniques are in daily use throughout the aircraft industry. Straightforward scale-up from the sizes and dimensional tolerances typical of fighter and commercial aircraft structures to those required for B-2 was complicated by the need to create and install larger-scale equipment, to use graphite lay-up tools to reduce mass, and to empirically solve problems caused by incomplete understanding of non-linear scale effects in de-bulking and curing.

In the absence of B-2 production, industry-wide composites fabrication capabilities for fighter scale components will be retained through ongoing commercial and military aircraft production (e.g., 757, 767, 777, MD-80, AV-8B, F/A-18, F-15, F-22). Developmental efforts by ARPA, NASA, McDonnell Douglas and Boeing may lead to commercial aircraft composite wings in production within 10 years. If so, industrial base capabilities for heavy bombers would be available, probably with improved affordability. If not, scale-up efforts to reconstitute specific capabilities for B-2 or a new heavy bomber will be required, similar to those originally accomplished on B-2.

In addition to B-2 and other production applications, composites will continue to be advanced in development programs such as the F-22, F-18E/F, V-22, and JAST/ASTOVL, which are developing composite technologies for fighter class vehicles. Also, NASA and ARPA are addressing the expanded use of composites in primary structures of engines and airframes for large aircraft.

These programs provide the necessary technologies to support either the restart of B-2 production or the development of a new heavy bomber. Overall there are no unique technologies involved with composites and their manufacture for the B-2 that are not available from the aircraft industry or that could not be reconstituted within a reasonable time.

Composite Structures



- **B-2 composite structures are the largest ever in a production program**
  - **scale-up was difficult and expensive**
  - **significant geometry and repeatability problems**
- **Materials should be available through support from programs like F-22, V-22, and Comanche**

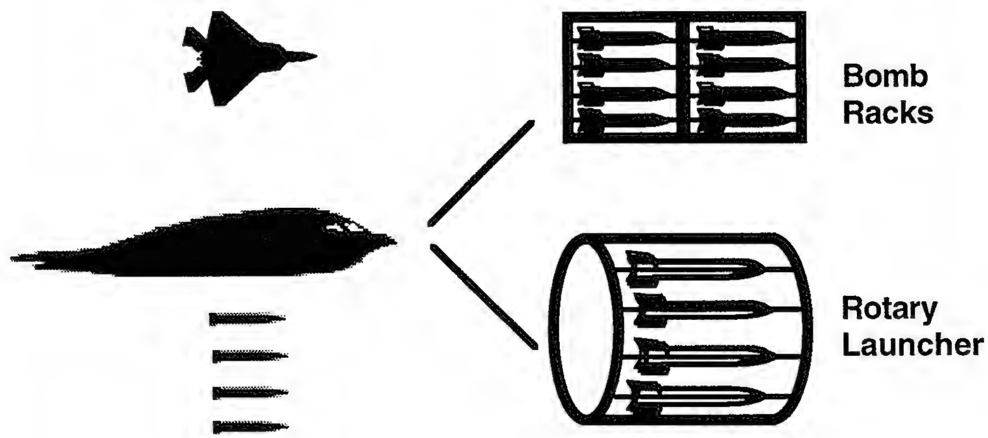
Restarting manufacture of composite structures of comparable size (e.g., commercial wing structures) will require relearning to address scale-up problems

Subsystems

A dozen discrete systems were gathered under the title “Subsystems” in the generic work breakdown structure (WBS) shown at the beginning of this report. Of these, only one -- the specific type of weapons carriage -- is unique to heavy bombers. Rotary launchers and large bomb racks are used in all operational U.S. bombers -- the B-52, the B-1B, and the B-2. Among these, only the B-2 ***must*** carry its weapons internally because of stealth requirements. With B-2 production complete, there will be no ongoing production of large bomb racks or rotary launchers. However, these are not technically difficult to produce and this capability can be reestablished when required.

Some of the other subsystems are more complex than those on other aircraft. For example, the B-2’s fuel management system ***continuously*** monitors and adjusts fuel storage to maintain stability of the bomber’s center of gravity. Nevertheless, the subsystems are basically common to other military and commercial aircraft. Supplier companies design or participate in the design of most of them, and also produce them. There is an adequate industrial infrastructure to support future bomber subsystems needs.

Subsystems



- Auxiliary power unit
- Wheels, tires and brakes
- Simulation and training systems
- Heat exchanger
- Electric generator and power distribution
- Environmental control system
- Oxygen generation and distribution
- Fuel management system
- Weapons carriage
- Hydraulic system
- Flight control

- Rotary launchers and large bomb racks are needed only by heavy bombers, and they are not technically difficult to produce

An adequate industrial infrastructure will support these various subsystems

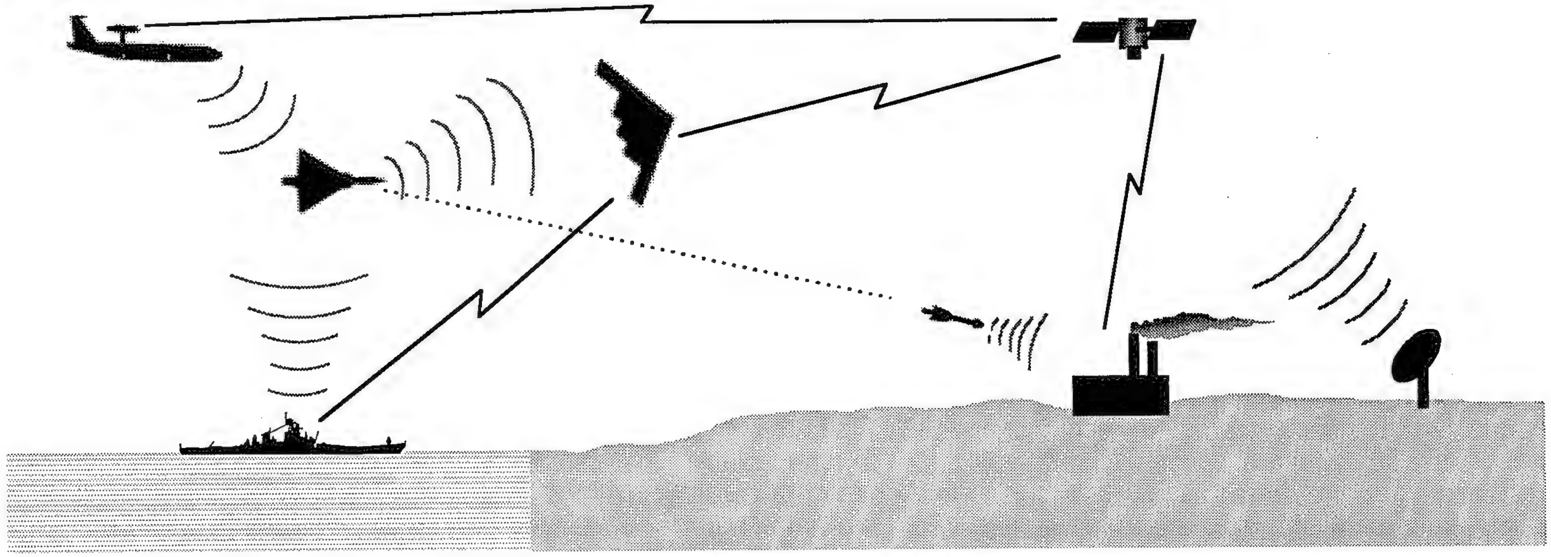
Electronics

The B-2's electronics systems are numerous and complex, but they are not fundamentally different from similar systems in other aircraft. The processes required to design and "build-up" to aircraft system level are essentially the same, even though the resulting systems may be very different.

Electronics for the B-2 specifically, and bombers in general, are a small part of the defense electronics sector and an even smaller part of the electronics industry. Rapid technology advancement and continuous growth are unquestionable electronics industry trends, but the small size of the military sector relative to other electronics markets may limit the priority and influence of military electronics buyers in the future. This has been a growing issue and will continue to increase in importance -- whether or not DoD continues B-2 production.

Another potential electronics issue is manufacturing and program management/systems engineering. While the lack of new systems in the future may limit the industry's experience base in these disciplines, electronics capabilities are expected to remain robust as modification and upgrade programs continue. Most companies in the industry will also utilize capabilities required by bombers in alternative aerospace and non-aerospace markets.

Electronics



- Electronic systems pervade the modern battlefield
- Military electronics technologies cut across all aerospace and defense sectors, as well as some commercial sectors (e.g., communications)
- Electronics subsystems are unique solutions to specific requirements and draw on available technologies

Bomber electronics are a small part of the total electronics industry, and require no unique industry capabilities

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Future Availability of Industrial Capabilities

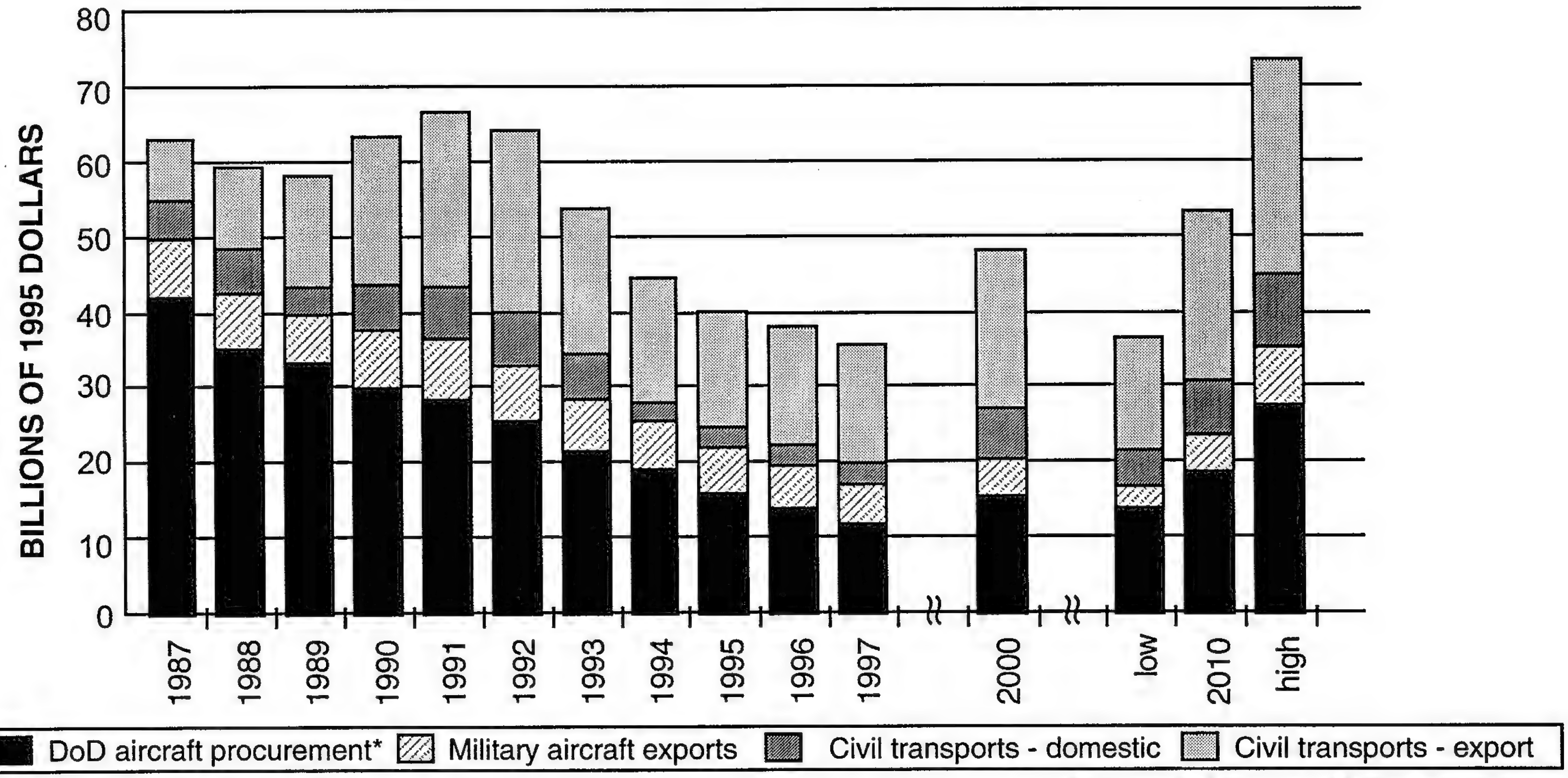
The future health of the aircraft industry is fundamental to the nation's potential ability to restart the B-2 or produce the next generation bomber. A healthy aircraft industry is needed to keep important suppliers in business and maintain the degree of engineering know-how and innovation necessary for advanced military systems.

The aircraft industry is reaching the low point of a long downward trend. DoD aircraft procurement in 1997 will be down approximately 70 percent from the 1987 peak (measured in constant dollars), while civil transport sales are expected to bottom out in 1996, down roughly 40 percent from 1992. However, forecasts show that the trend will change in the near future. After 1997, sales are projected to recover strongly, up perhaps 40 percent by the year 2000 from the 1997 low and up even more over the following decade. Despite current declining sales, the financial health of the aircraft industrial base remains relatively strong. Through acquisitions and restructuring, many companies have actually strengthened their overall financial position and aircraft-related capabilities. Ongoing consolidation within the aircraft base is creating a smaller, leaner, financially-sound industry.

Commercial U.S. and export sales have become increasingly important to the financial health and overall capabilities of the industry. Commercial sales have grown from approximately 20 percent of total aircraft sales in the mid-1980s to over 50 percent today. The export portion of aircraft sales has doubled from 25 percent to more than 50 percent over the same period. With a substantial increase in world demand for civil transports forecast over the next 20 years, the commercial and export shares of U.S. aircraft sales are likely to remain at the current levels into the future.

Future Availability of Industrial Capabilities

Aircraft Industry Sales Growth



*forecast based on 1 June 1995 data

Source: AIA, Boeing, McDonnell Douglas

Aircraft industry at its nadir supports bomber production. Future growth indicates that industry will become more robust and capabilities will remain available

TASC

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Aircraft Industry Workforce

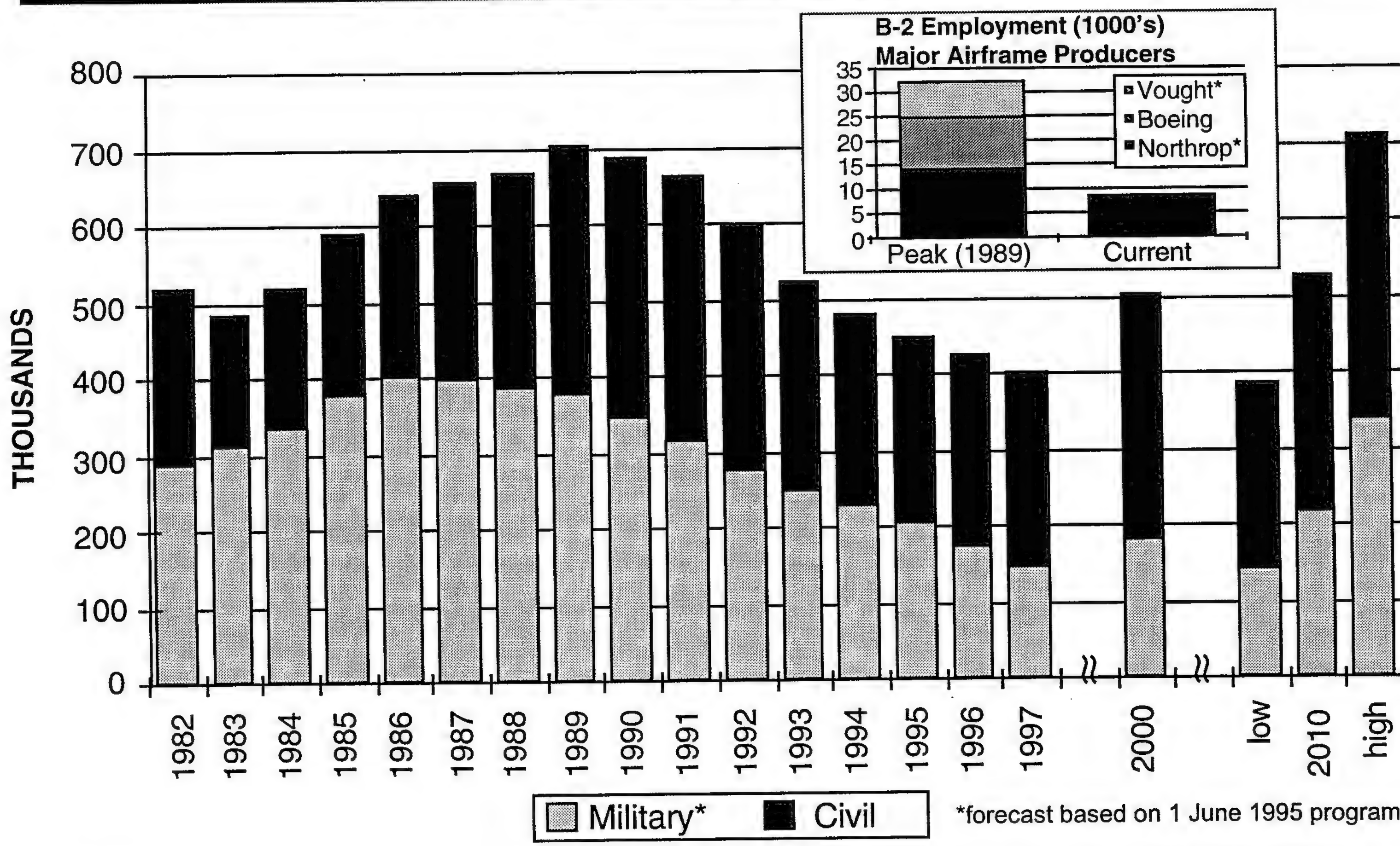
The aircraft industrial base has been restructuring itself in response to the changing demand mix and declining sales. Aircraft industry employment has been cut by one third over the past six years and additional cuts will occur as sales continue to decline. When levels of employment bottom out in 1997, employment will have been in decline for eight straight years. (The decline in the dedicated B-2 workforce of the three principal airframe structure fabricators, shown in the insert, contrasts with the industry trend.) The 75 percent decline in the B-2 workforce reflects the completion of all fabrication work. The loss of experienced personnel and the inability to add a commensurate number of new employees during this period, may affect capabilities and responsiveness when sales begin to increase.

The aerospace industry, as a whole, has experienced a shift in the employment mix as sales have declined. The production worker portion of the total has fallen from 45 percent in 1990 to 42 percent today. In contrast, the number of scientists and engineers currently stands at 22 percent of the total, up from the 18 percent share of the mid-1980s. The relative stability of scientists and engineers can be explained by the fact that R&D budgets have continued to support the technical workforce in the face of substantial production cutbacks.

Human resources are generally thought to be the aircraft industry's most important asset, so the protracted decline in employment is reason for some concern. Another potentially disturbing trend is a decline in the number of military aircraft programs, which limits the diversity of experience for new industry employees. A final trend to watch carefully is the declining importance of military aircraft funding in the overall industry sales mix, because such funding supports a disproportionate share of the R&D personnel in the aircraft industry. Although the industry turnaround that is expected in the late 1990s and beyond will stabilize the overall industry and ensure the retention of design and production capability, a review of industry sales and employment makes it clear that industry sales -- especially R&D -- will make a great difference in the cost, time, quality, and degree of innovation in future bombers and other military systems.

An important positive factor in the employment picture is the growing productivity of the aircraft industry workforce. Although the gains shown for U.S. industry are still relatively modest, foreign manufacturers are showing dramatic productivity increases in their state-of-the-art facilities. Advanced manufacturing methods must be adopted by domestic producers if they are to compete effectively in the international market. In fact, productivity increases in the U.S. aircraft industry are even now taking hold.

Aircraft Industry Workforce



*forecast based on 1 June 1995 program data

Aircraft industry workforce can absorb potential B-2 restart or new bomber; increasing productivity provides added confidence

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Industrial Capabilities Findings

Structured interviews with aircraft industry executives and government program managers, engineering analyses of B-2 and other aircraft, and economic and financial analyses all pointed to the same conclusion: there is nothing about the B-2 that is unique or that cannot be recreated by industry if required. When one examines the military aircraft work breakdown structure (WBS) below the third level, it is clear that, although B-2 WBS elements may possess numerous specific features to enable the aircraft to meet its mission requirements, the capabilities to create a B-2 are found across companies that support a wide range of aircraft programs, often with very similar products. In short, there is no unique bomber industry. Rather, the aircraft industry supports B-2 as a relatively small component of its annual sales.

This commonality among aircraft means that "bomber capabilities" will not remain static even with an extended gap in bomber production. Technologies in the areas of stealth, composites, avionics, software generation, and the like will continue to evolve through their application to other aircraft programs such as F-22, while pressures for improved affordability will improve manufacturing processes and provide impetus for acquisition reform measures.

This conclusion is predicated upon the continuation of a healthy, world-class domestic aircraft industry into the future. All of the aircraft industry forecasts examined by the study team conclude that the industry will experience a turnaround beginning in 1998, chiefly fueled by increasing commercial sales. Recent restructuring by major firms in that industry has reduced the overall number of active companies, but it has diminished chronic problems with overcapacity and led to a leaner industry, without any loss of critical capabilities.

A high-technology industry is always forced to struggle when new, immature technologies are introduced as a means of meeting a new generation of performance goals. When B-2 production got underway, these technologies required that industry develop new capabilities for manufacturing the new system and its key components. Today, these technologies and their underlying capabilities are more widely used.

Finally, in the absence of a dedicated bomber industry, a future bomber will rely on technologies and capabilities being developed for next-generation application to the F-22 and JAST. Although these fighter aircraft programs may not be directly applicable, advances in stealth, propulsion, and other areas will be tapped for use in a future bomber.

Industrial Capabilities Findings

- **There is no distinct "bomber industry"**
- **Industrial capabilities required for bombers do not depend on continued B-2 production**
- **Capabilities will be maintained and enhanced by other military and commercial aircraft programs**
  - Provide a base to support B-2 restart or new bomber if needed
  - Specific design and manufacturing solutions for a future bomber will be complex
- **Industry projected outyear growth gives added confidence that needed capabilities will be available**
- **B-2 does have specific features that differ from other aircraft in areas such as stealth, structures, electronics, and weapons carriage; however,**
  - Some of these features are more widely used on other military aircraft now
- **Continued capability in these areas will depend on selected military work on other military programs, particularly F-22 and, later, JAST**

Potential Restart

The potential for a B-2 restart in the future, even if not highly probable, is one that should be explored. Higher than anticipated attrition in the bomber force, a major worsening of the threat, or some other unforeseen events could cause a B-2 restart to appear as a viable option.

Any production activity beyond the currently programmed force of 21 B-2 bombers would, by definition, be a program restart. All of the suppliers to the airframe have completed production, some as long ago as 1992, and the three major airframe fabricators (Boeing, Vought, and Northrop Grumman) made their last deliveries to the final assembly facility more than a year ago.

There currently are no plans to restart B-2 production. The Department of Defense does not consider restart to be a current option, but this study examined the feasibility of a restart program at several future dates.

The study analyzed restart from several perspectives. First, case studies involved on-site interviews with individuals responsible for the restart of the B-1, C-5 and U-2 programs. This "lessons learned" approach identified actions which eased program restart as well as those that could potentially be beneficial in restarting the B-2.

A second approach involved analysis of data gathered from Northrop Grumman and major subcontractors. However, pending a final decision on recent Northrop Grumman proposals to produce 20 additional bombers, the company has concentrated its efforts on contractual activities in the areas of preservation (near-term restart) and curtailment (program shut down). Although there are overlaps between preservation and curtailment, little hard data was available on either shutting down the program in a manner to facilitate starting up again in the mid- to long-term.

In an analysis of shut down options, the team also analyzed the status of B-2 tooling and other government- and contractor-owned equipment to determine the cost-effectiveness of retaining those assets for a potential future start-up. Much of the tooling is no longer being used and in some cases is in danger of being disposed of by contractors who no longer participate in B-2.

Finally, an analysis of the costs, schedules, and risks of various restart options was performed. The analysis differed from others by looking at mid- to long-term options, rather than near-term (1997). However, the overall values are consistent with the earlier analyses.

Potential Restart

Current Status of B-2 Manufacturing Capability

The B-2 program is winding down and most capabilities applied to B-2 during its peak funding years have long since diverted to other programs.

Essentially all B-2 fabrication work on production aircraft is complete; about 70 percent of airframe tools are inactive; work at Boeing, Vought, and Northrop Grumman (Pico Rivera) is nearly complete; and major structural assembly (e.g., wing attachment) is complete for all aircraft at Northrop Grumman. In addition, Northrop Grumman is planning to vacate the Pico Rivera facility used in B-2 production -- regardless of any restart decision.

A truism applicable to all completed production programs is that the associated industrial base shuts down from the bottom up. That is, the supplier bases for Northrop Grumman, Boeing, and Vought completed their deliveries in time for their products to be incorporated into the major subassemblies of the airframe. Also, since airframe components and subassemblies are less likely (than electronic or mechanical systems) to be in continued production for spares or replacement parts, there currently is a negligible level of ongoing airframe fabrication work.

Current Status of B-2 Manufacturing Capability

- **B-2 fabrication of major structures is complete. Assembly work by Northrop Grumman being completed**
- **Major facilities are being converted to other use**
  - Boeing has allocated B-2 floorspace to 777, F-22 and other programs
  - Northrop Grumman Pico Rivera facility to be closed by end 1997
  - Northrop Grumman Dallas facility (Vought) future uncertain
- **About 70% of tooling is inactive**
- **Workforce reduced 75% from peak ~32,000 (1989) to ~8,000 (today)**
- **Most subcontractors finished -- some since 1992**

The Baseline for a B-2 Restart

For the remainder of the century and for several years beyond, there will be a moderately robust base of industrial activity upon which a production restart could build. The B-2 program has been largely "concurrent", with a substantial level of development activity occurring during production. Of the 21 air vehicles (AVs) in the program, only AVs 20 and 21 will be delivered in the fully developed Block 30 configuration. AVs 2 through 19 will be cycled back to Northrop Grumman for upgrade from either Block 10 or Block 20 configuration to Block 30 (AV-1 will not become an operational bomber). Beyond this defined block upgrade program, there are other research and development activities as well as some production activities and initial spares acquisition. In all, these post-production activities add up to several billions of dollars.

In addition to block upgrades and related work, contractor-operated programmed depot maintenance will begin in 2002 and will not complete until 2005, and contractor software maintenance will continue indefinitely. Together these are multi-billion dollar support efforts. Finally, sustaining engineering is funded in the FYDP at about one billion dollars and is forecast to be a multi-billion dollar effort in the out years.

Overall, these extensive activities, combined with normal material support operations of the B-2 supplier base and other closely related activity in the F-22 and JAST programs, provide a substantial base for restart.

The Baseline for a B-2 Restart

- **Significant capabilities will be retained through upgrades and depot maintenance activities**
  - Block 30 deliveries and retrofits continue through year 2000 (multibillion dollars for R&D, production, and initial spares)
  - Contractor-Operated Program Depot Maintenance (PDM) cycle continues through 2005
  - Contractor-operated Software Integrated Support Facility (Ok City)

  Multibillion dollar support effort

  - Sustaining Engineering ($1B in FYDP, multibillion beyond)
- **Some key suppliers will be supporting operation of B-2 aircraft**
- **Other future stealth aircraft in development and production -- F-22 and JAST**

Some DoD Experience with Restarts

While there is no current intention to restart B-2 production, it should be noted that there have been other unanticipated aircraft program restarts in the past. Rand recently concluded an assessment of several of these restarts and concluded that:

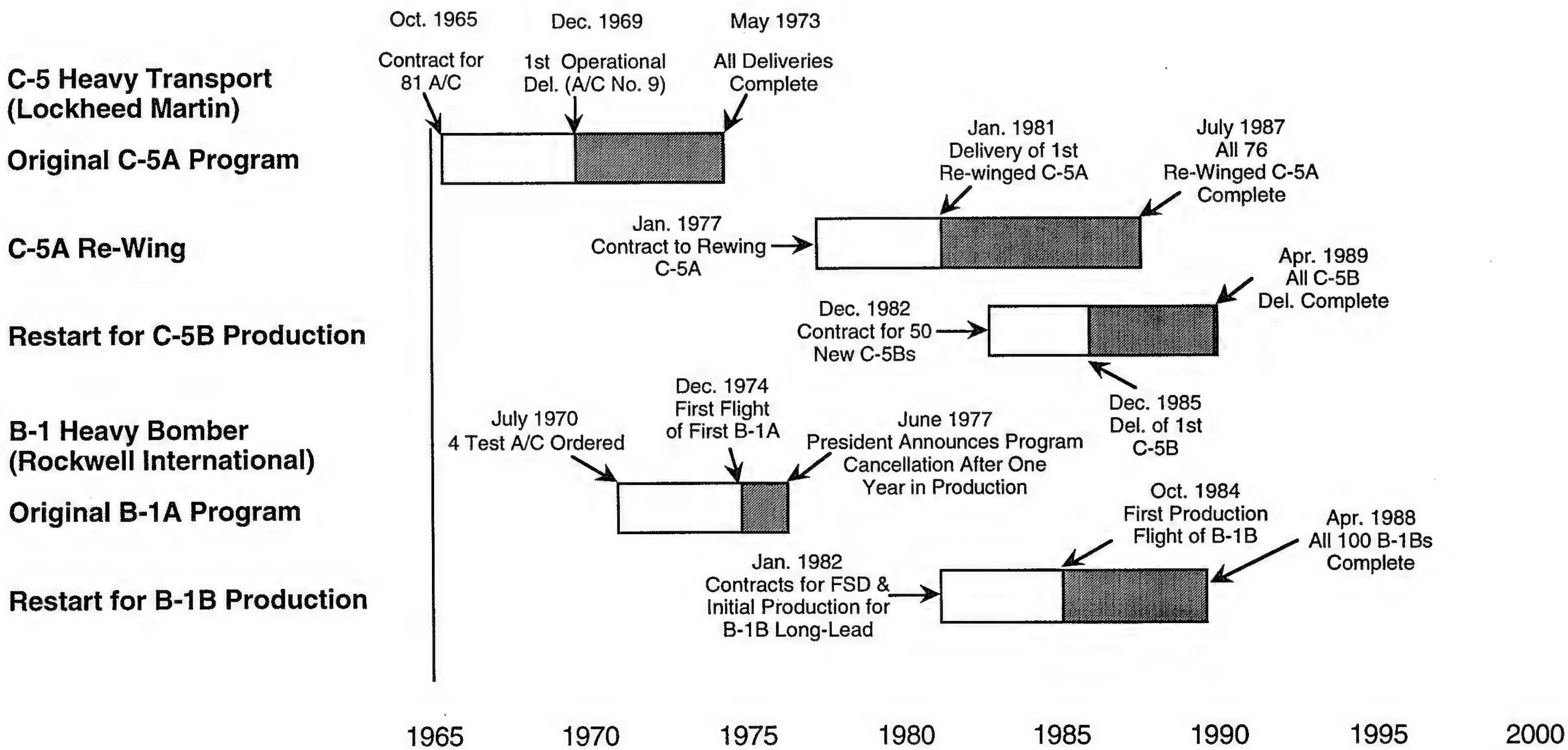
- Restarting an item already in service presents very low risk compared with developing and producing a new system
- It takes about one to two years less to produce the first unit for restarted production than for original production
- Restarting aircraft programs that have previously achieved full production capability and then been shut down should result in follow-on programs that require less time from program start to first delivery and should be significantly less expensive than the original program
- The investment required to preserve essential items is quite modest compared with the original acquisition cost, and a very modest dollar investment at shut down could save hundreds of millions of dollars if a restart is required
- To ensure smart shut down, DoD should fund contractors to preserve those documents, tools, etc., that are needed to restart production.

This chart shows the timelines for the shut down and restart of the C-5 transport and the B-1. The B-1 bomber is most relevant to a potential restart of the B-2, although it is not fully analogous. The design of the B-1A was frozen in January 1971, but the program was cancelled in mid-1977 after only one year in production. Three flight test aircraft, one ground test aircraft, and 27 engines had been ordered. Rockwell, the prime contractor continued to perform development, flight test, studies, and IR&D, while vigorously advocating a restart. Personnel were loaned to other aerospace companies and assigned to other Rockwell work.

In January 1982, Rockwell received contracts for Full Scale Development (FSD) and initial production for long-lead items for the B-1B and a total of 100 B-1B aircraft were later ordered. 20,000 people were hired, a new facility was built, and an industrial base network of 3,500 suppliers and subcontractors was established. First production flight of a B-1B was October 1984, and all deliveries were completed by the end of April four years later.

Proportional reductions in schedules and costs might be anticipated for a B-2 restart in the future, as opposed to a new bomber program. Obviously, as time goes on and technology advances, major modifications and/or a new design become more and more attractive.

Some DoD Experience With Restarts



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Enhanced Curtailment Program

A curtailment decision in January 1992 reduced the B-2 production program from 75 to 21 air vehicles. A curtailment plan subsequently developed by the B-2 SPO is planned to extend from FY 1993 to FY 2002, with annual options. The curtailment program is not and was never intended to be a "restart" program; rather it is a plan to achieve orderly phase down and close out of the production effort and to ensure the ability to provide operational support for the life of the B-2 weapon system. At very modest cost, however, the existing curtailment plan might be enhanced to provide capabilities some other programs have characterized as "smart shutdown."

The term "smart shut down" (or "enhanced curtailment") has come into common usage to describe activities that facilitate program restart, but there is no universally agreed upon definition of what it is. In some programs, for instance, smart shut down has been defined to include videotaping (and narrating) all critical manufacturing tasks to ensure that as much as possible of the process technology is retained for potential future use. For the B-2, this would be an expensive undertaking, but, more to the point, it already is too late to do: most critical processes already have been completed. In still other programs, the term has been defined to include the procurement and storage of long-lead components such as large castings and forgings. For the B-2 program, a detailed analysis of a long-lead program has not been performed, but a broad estimate of potential cost is in the $400 million range. In the current budget environment, long-lead procurements of this magnitude are probably not feasible -- or desirable -- for a "potential" restart at some undefined future date.

Considering both the probability and the affordability of a future restart of the B-2, the definition of "enhanced curtailment" or "smart shutdown" developed for this study focused on relatively inexpensive planning and analysis activities, the layaway of government-owned tooling in government-owned facilities, and cost/benefit analyses focused on the possible procurement of some key contractor-owned tooling and test equipment. Such modest efforts would greatly facilitate a future restart of the B-2, should it be called for by changed circumstances.

Enhanced Curtailment Program

- **Current "curtailment" program**
  - Closes out current B-2 production program while ensuring support for remaining development, test, and operations
  - Stores a set of government owned production tools (interim storage thru 1997)
  - Totals $160M ($85M obligated to date) through FYDP
  - Curtailment is shut down (**not** restart plan)
- **Enhanced curtailment option:**
  - Would augment curtailment program to reduce restart time and cost
  - Could potentially save 1-1.5 years in a 6+ year restart program
  - Would include key subcontractors and suppliers
  - Would begin with a detailed cost/benefits analysis
    - Layaway/storage government-owned tooling
    - Plan for long-lead procurements
    - Assess potential costs/benefits of acquisition of depreciated contractor owned tooling and test equipment, including all critical suppliers

B-2 Restart Findings

Neither the program office nor the prime contractor have completed comprehensive assessments of the feasibility or affordability of restarting B-2 production at some uncertain date in the mid- to long-term future. However, all of the available data indicate the clear feasibility of doing so.

Having assessed the feasibility of a restart, the study also concluded that both the cost and time required for a restart could be significantly improved through a modest enhancement of the curtailment plan focused on a comprehensive planning effort and a modest investment in layaway and storage of tooling.

B-2 Restart Findings

- **Industry has the capability and experience to restart B-2**
  - Experience with restart of several military programs
  - B-2 prime contractor will have continued depot involvement through 2005 and major mods currently planned through 2000, with long-term maintenance plan to be defined later
- **Restart time and costs could be reduced through enhanced curtailment program**
- **Would require funding above the current cap (about $10 million initially; with a possible lower level recurring cost level)**

Potential Next Generation Bomber

The third area of investigation was industry's ability to produce a next-generation bomber, and the extent to which industry capability would be jeopardized by the termination of the B-2 program after only 21 aircraft. Such a program decision, coupled with a decision not to restart the B-2, would result in a gap of at least a decade (and perhaps two) in bomber production, and a much longer gap in bomber design and development. Specific concerns include retention of design capabilities over that time period and the need to maintain technology development in areas of particular importance to bomber aircraft.

Uncertainty about these factors is heightened by the nation's inability to forecast the threat that will face the U.S. into the next century, the ability to maintain the programmed bomber force over this extended time period, and the mission requirements that any new bomber will be expected to meet. Today, the government has identified three main options for enhancing the bomber force in the future. The first, discussed in the previous section, is to resume B-2 production beyond the 21 programmed aircraft. A second alternative is to initiate a new heavy bomber program, ostensibly directed toward a design capable of penetrating air defenses envisioned beyond 2010. A third option redefines the "heavy bomber". This option entails developing a long-range, high-capacity airframe that would provide bomber-style global reach, but armed with advanced precision standoff weapons that eliminate the requirement for the launch platform to penetrate air defenses. Conceivably, this design could be a derivative of a large commercial transport or airlifter.

The study team approached this task by assessing technology programs that could potentially contribute to a heavy bomber and performing a series of cost and schedule analyses for the heavy bomber option. Importantly, these analyses included two excursions. The first analyzed the impacts of current acquisition reform measures on schedule and costs, and the second hypothesized the savings that could be achieved through an "affordability R&D" program that would begin immediately and continue on to system development.

Potential Next Generation Bomber

Capability to Support Future Bomber Options

Given the uncertainty about the nature and timing of the next bomber, one cannot provide a definitive assessment of industry's ability to support it. Nevertheless, three points can be made. First, there is no evidence that a continuation of the B-2 program beyond the programmed 21 aircraft will have any positive effect on industry's ability to build a new bomber in the future. Continued production of B-2s would restore and requalify a contractor and supplier network that has the capability to produce a B-2 based on mid-1980s technology. There is no assurance that these same companies would be involved in design and production of a future bomber, or that the requirements of such a system would bear a meaningful resemblance to B-2. B-2 production would also do little to sustain critical design, development, and integration skills that would be of paramount importance in a new system. A decision to buy more B-2s now will result in more B-2s -- not stronger capabilities to design and produce bombers in the future.

Second, the aircraft industry has been responsive to DoD's needs in the past, and monitors these needs as a matter of course. Regardless of technical challenge -- which was possibly pushed to the limit when B-2 was initiated -- industry has repeatedly demonstrated its ability to assemble a team that can meet the requirement, albeit at a greater cost and longer time than desired. Engaging leading aerospace firms in concept definition and requirements formulation will allow industry to "think ahead" and create new capabilities that are not otherwise active within the base. The size, duration, and profitability of a large aircraft program -- at a time when there are fewer than before -- makes responsiveness an essential ingredient in business success. Early involvement of industry also encourages the use of mechanisms such as DPA Title III to create qualified production sources for new materials or items that a new bomber is likely to require. In short, aircraft prime contractors do not routinely turn down work because the challenges are too great, and they are less likely to do so in an austere budgetary environment for defense.

The third point is that the pending reduction in both government and industry R&D causes uncertainty that new technologies will be created and sufficiently matured to allow insertion into the next bomber. Technologies of interest to the bomber community are being worked under DoD R&D funding and the F-22 and JAST programs; although the technologies are similar, the orientation of these programs toward fighter aircraft is unlikely to accurately reflect the technical needs of the next bomber. Although JAST and F-22 are essential to moving many bomber-related technologies ahead, it is also necessary to extend this work so that it equally applies to the scale, complexity, and performance requirements of bombers.

Capability to Support Future Bomber Options

- **Various options for expanding future bomber force:**
  - Upgrade programmed aircraft (current strategy)
  - Add more B-2s or a major mod version (Restart)
  - Initiate a new manned penetrating bomber program
  - Field a long-range, high-capacity standoff weapon launch platform
  - Other industry concepts
- **Different concepts may tap different industry capabilities (e.g. standoff option places greater reliance on weapons capabilities vice airframe)**
  - Data suggest existing industry can support all options
  - Without “affordability” program, traditional cost growth will persist
- **This study focused on “B-2-like” heavy bomber**
  - Well defined alternative that is logical outgrowth of B-2 capabilities

Industrial Capability for A Next Generation Bomber

The military aircraft sector of the aircraft industry is near its nadir (based upon program data as of 1 June 1995) and should provide an adequate research and development base for continued advancement of key bomber-related technologies such as low observables and advanced composites. Key programs include the F-22, F/A-18E/F, and JAST. The same programs will also be critical to maintenance of the production base.

This assessment derives from a strong consensus among the industry experts consulted in this study that there will be at least two strong, healthy military aircraft producers for the foreseeable future. The consensus view was fully supported by a number of documented forecasts, including DoD program and budget data. Looking into the future, attention has focused on the F-22 and JAST programs, which are indeed critically important to the aircraft base, particularly in such areas as integration of large, complex military aircraft programs, software development and integration, low observables, and composite structures. However, there will also be a host of other programs which will contribute to the overall health and competitiveness of the design, engineering, and production base, such as the F/A-18 E/F, V-22, AV-8B, C-17, special purpose aircraft, and helicopters. Substantial growth in the commercial aircraft industry sector also will be a major contributor to the overall health and competitiveness of the aircraft industry.

Given that these capabilities will be maintained, it should be noted that bomber aircraft are extremely complex systems, and therefore are time-consuming and costly to develop. An area of future potential concern, therefore, is the affordability of a future bomber. Historical trends are not encouraging.

Industrial Capability for a Next Generation Bomber

- Engineering capability to develop a next generation bomber will be adequately maintained by continuing activity on the B-2 and by development of the F-22 and JAST
- Production capability will be adequately maintained by the same programs and by commercial aircraft programs
- However, historic cost curves give cause for concern about the affordability of a next generation bomber

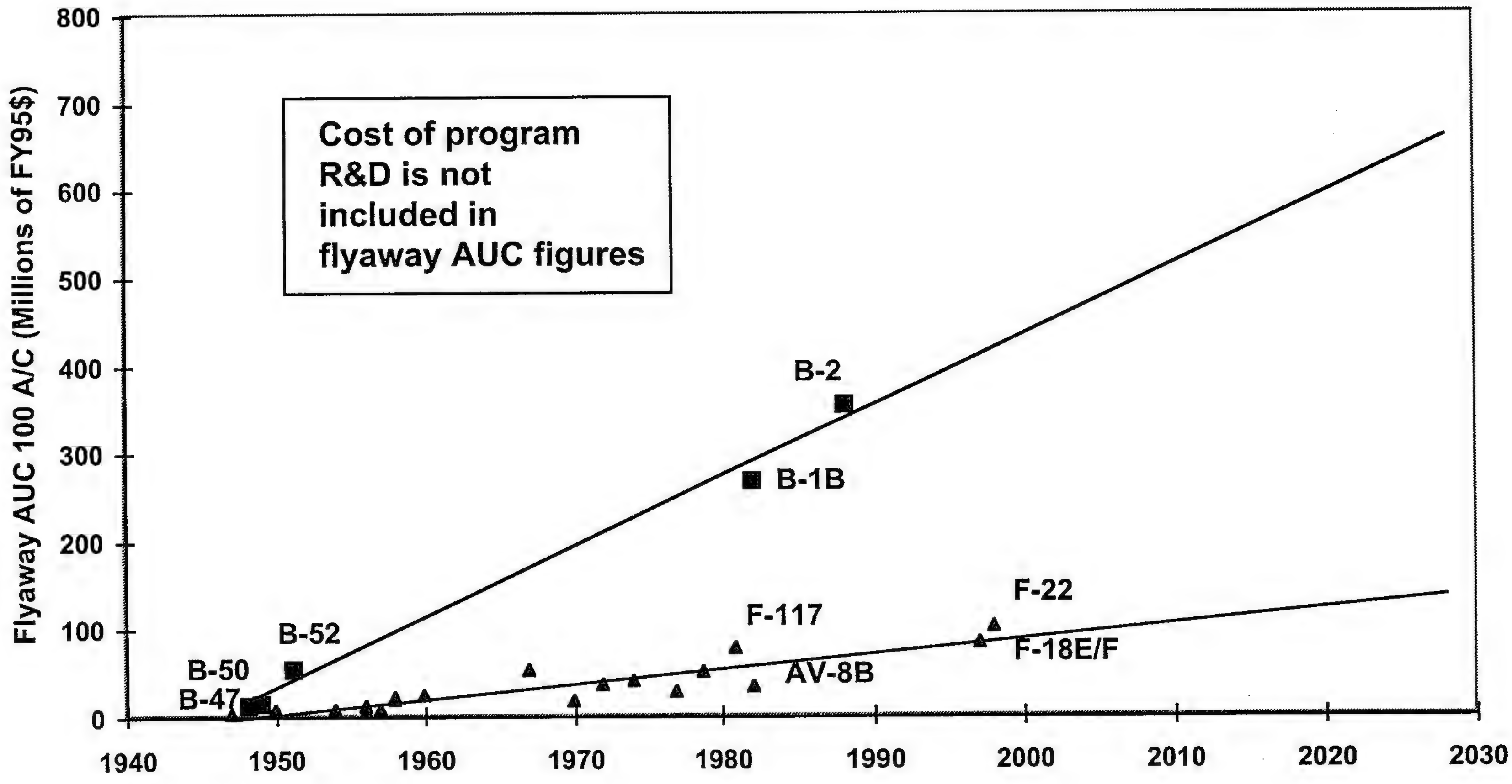
Heavy Bomber and Fighter Cost Trends

The heavy bomber and fighter cost trend data shown on this chart were gathered from the TASC, Inc. data base and from the Seventeenth Edition of the "*U.S. Military Aircraft Data Book, 1995*", by Ted Nichols and Rita Rossi and published by Data Search Associates. The data were normalized in 1995 dollars (using the latest DoD inflation rates for aircraft procurement) for the flyaway (non-recurring and recurring) average unit cost (AUC) for the first 100 production units. The AUC was plotted at the point of the first year of production.

Both cost and performance of military aircraft have been increasing in a predictable way. The trend lines in this figure show how both cost and performance of heavy bombers and fighters are growing from generation to generation. Heavy bombers are on a steeper cost growth slope than fighters.

The insert notes that program R&D costs are not factored into the flyaway AUC costs, but, following traditional patterns, they are indeed a major portion of the affordability equation. The R&D costs associated with any new bomber program predictably will be proportionally as great as those for the B-2.

Heavy Bomber & Fighter Cost Trends



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Affordability R&D for Potential Next Generation Bomber

Any discussion of technologies required for a next generation bomber must start with affordability. Although there are many factors that mitigate against production of more B-2s, the $44.4 billion cost of the initial 21 aircraft (which includes ~$24B for R&D), with many more billions required for operations and support, was a major consideration in DoD's decision to limit further buys. In the past, performance (and cost) have been driven by the growing sophistication of the threat, but evidence suggests that affordability limits have been reached, and often exceeded.

The idea behind an affordability R&D program is not to cut performance to bring the costs into line, backing off on the nation's longstanding commitment to qualitative superiority, but to reduce costs by designing and producing systems in a smarter way, taking advantage of appropriate manufacturing technologies, applicable commercial practices, civil-military integration, and acquisition reforms.

The affordability R&D program recommended by the study team involves an effort to find more affordable ways to develop, transition, and apply technologies that are likely to be required for a next generation bomber. The effort would help to sustain an active R&D base during a potentially extended gap in bomber production and break the cycle of escalating weapon system costs by ensuring that the next bomber is not more expensive than the last. It could be conducted in close coordination with JAST development activities to centralize and leverage all national efforts in affordable aircraft R&D. The study concluded that a modest investment to define concepts and build affordability into ongoing research would be beneficial. This annual budget for this affordability R&D program would be revised upwards as the likelihood of a next generation bomber increases. Ultimately, should it be decided to go ahead with a next-generation bomber, this effort would transition into the next bomber's R&D phase, cutting time and money from a traditional "standing start" R&D program.

Affordability R&D for Potential Next-Generation Bomber

- **The ability to build any heavy bomber in the future is threatened by increasing costs**
- **An "affordability" R&D program can prevent a next generation bomber (if required) from following historic cost trends**
  - A risk reduction/low cost <u>heavy bomber affordability R&D program</u> could be established (with a design-for-manufacturing focus)
  - Program could potentially be structured as a complement to JAST
  - Added R&D cost (for the bomber-unique, affordability design effort) would be a few million per year (initially under $10 million/year)

DoD Experience in Large Bomber Aircraft

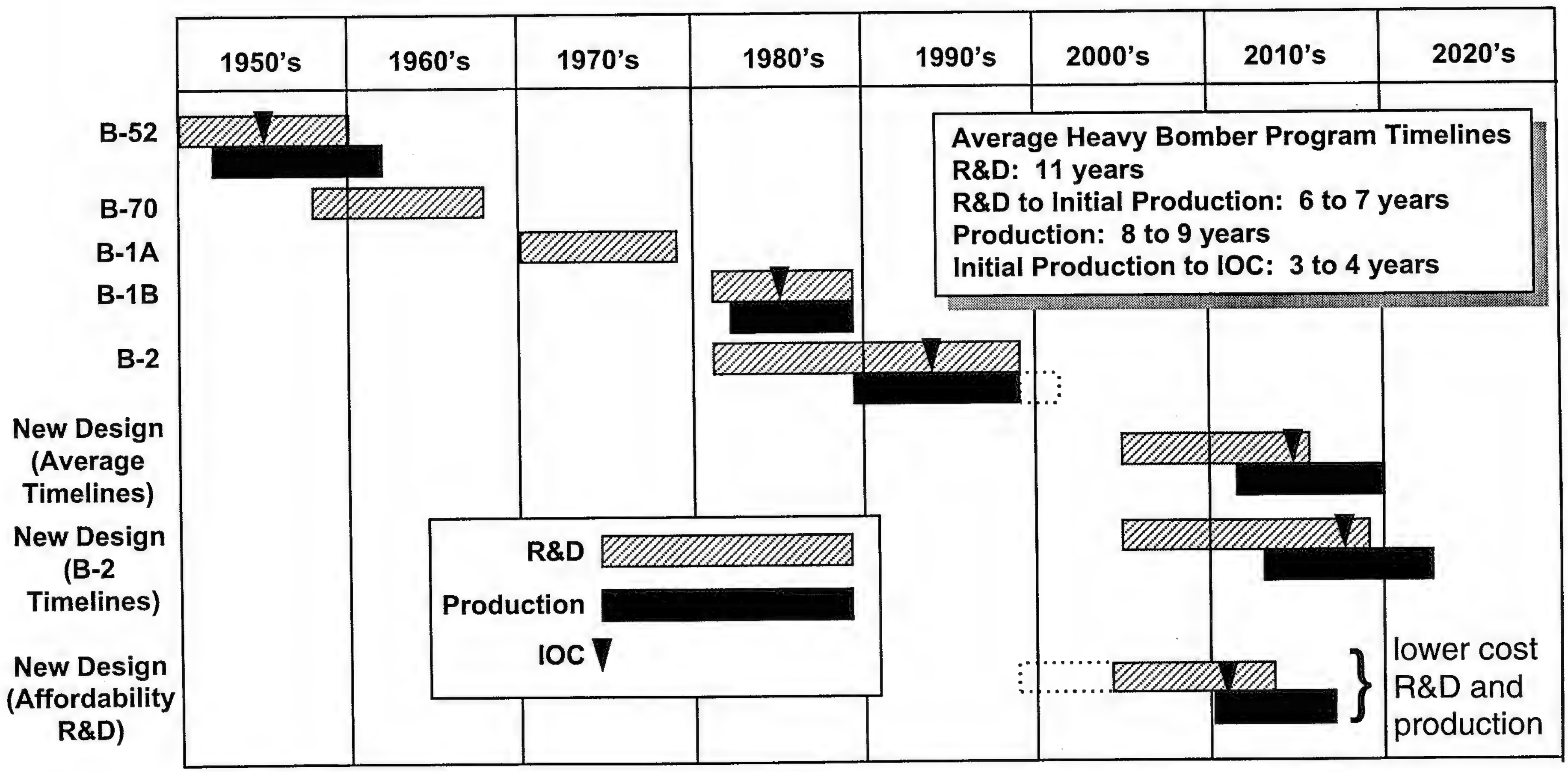
This chart depicts R&D and production timelines for almost 50 years of bombers, and projects the hypothetical schedules of future bombers as well.

With the exception of small gaps between the B-70 and B-1A programs and between the B-1A and B-1B and B-2 programs, heavy bomber R&D has been continuous since 1950. Average duration of the five heavy bomber R&D efforts has been 11 years. Average duration of the three heavy bomber production programs has been between 8 and 9 years. If the B-1A is included as R&D leading to the B-1B, the average duration of R&D prior to production for the three heavy bombers produced is between 6 and 7 years. Given IOC dates of 1955 for the B-52, 1985 for the B-1B, and 1994 for the B-2, the average period between initiation of production and IOC is between 3 and 4 years. Using these average values (based on a very small sample size), one can project an IOC between FY14 and FY16, and final deliveries between FY19 and FY21. The projection is based on an assumed earliest new heavy bomber program start of FY05 and initial production no earlier than FY11 or FY12. This estimate, given recent heavy bomber program experience and current R&D budget constraints and priorities, has to be regarded as very optimistic. Using B-2 timelines as more representative of current realities would give an estimate of FY13 for initial production, FY18 for IOC, and FY23 for final deliveries. The 10-year B-2 production program figure, however, is somewhat misleading in that B-2s delivered early in the production run will be returned to Northrop Grumman to be brought up to the final Block 30 standard. This activity that, in truth, will stretch B-2 production to 12 years, as is indicated by the dotted extensions to the production bars on the chart. Thus, it is fair to assume that, if there were widespread political sentiment in favor of a new heavy bomber program, combined with resources on the order of those put forth to develop the B-2, the new aircraft would be integrated into the Air Force heavy bomber fleet between FY20 and FY25, well after the B-52's fiftieth birthday (and presumed retirement).

It is inevitable that DoD will view these timelines as unacceptable, and identify ways of reducing schedules and costs. We have included a notional timeline for a new bomber that results from an extended affordability R&D program. If DoD intends to continue to procure bombers in the future, the timelines shown in the figure for the "affordability bomber" must at least be met -- and more often exceeded.

DoD Experience In Large Bomber Aircraft

Bomber Development and Production Timelines



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Next Generation Bomber Findings

The strong outlook for the aircraft industry, fueled by commercial and export sales growth, will sustain production capabilities that will be needed for military aircraft in the future. No additional actions are considered necessary to ensure that industry will respond to a requirement for a new bomber.

The second finding concerns a critical requirement to maintain a technology base in areas that are critical to bombers, and may not be required for other aircraft types. The maintenance and advancement of critical military technologies (e.g., stealth) could be slowed as fewer military aircraft enter production. For this reason, programs such as F-22 and JAST are essential to further these capabilities and maintain them in the aircraft base at the necessary level.

Since F-22 and JAST are concerned with the application of key technologies to fighters, an adjunct program may be desirable to address the specific requirements of bombers and, more importantly, to improve the affordability of these systems. It is possible that a new bomber will be required at some point in the future (if for no other purpose than to replace aging B-52s), and it is unlikely that the nation will ever be able to comfortably afford an aircraft whose cost follows the traditional profile shown earlier. The period when bomber production is winding down is a logical time to implement a modest program to both further bomber-related technologies and to make them more affordable for the future.

Next Generation Bomber Findings

- F-22, JAST, and/or other related activities in L.O., composites and other technologies, together with B-2 maintenance activity, are expected to maintain the industrial base for critical technologies at an adequate level
- The aircraft industry production base is expected to be sufficiently robust to produce a potential next generation "B-2 like" penetrating bomber in the future
- The engineering activity cited above will not, however, fully address the affordability issues associated with bomber aircraft. With bomber programs in an indefinite hiatus, a future bomber would benefit from targeted R&D (perhaps $10 million/year initially) to improve the affordability and maturity of critical bomber technologies

Summary

Very broadly, the study concluded that aircraft prime contractors in the United States historically have been very flexible in their ability to develop and produce different types of aircraft. Because of their flexibility, there has not been a distinct bomber industry; rather, there have been companies who have been producers of bombers during specific periods of time. In the lower tiers of the aircraft industry, firms tend to specialize in niche product lines (radar, propulsion, landing gear) but not in particular types of aircraft. These broad conclusions are reflected in the overall study findings.

Summary

Summary of Overall Study Findings

The results of this bomber core industrial capabilities study have been unequivocal. In an extensive outreach program to industry, outside experts, OSD, and the Military Departments, we found nearly universal agreement with our findings.

First, we found that the bomber industry is not a distinct entity that would be saved or lost by a decision on B-2 continuation. Rather, bomber programs are served by the same companies that participate in other aircraft programs, from primes to lower tiers. Except for normal movements in and out of the industry, these companies will continue to exist as elements of the aircraft industry for the foreseeable future, remaining available to support a B-2 restart or future bomber.

Given the diverse customer base of firms that have supported B-2, the end of B-2 production is unlikely to affect the capability to develop and produce bombers in the future. In fact, the B-2 program is winding down and many of these same companies ended their B-2 work as long ago as 1992. Northrop Grumman's recent proposals indicate that most of these firms are still viable and would still be available to support additional B-2s if need be.

Aircraft industry economic projections indicate that the downward trend of the last ten years is reversing; growth in sales and productivity are now anticipated. Aircraft primes and suppliers have shown great flexibility in undertaking new bomber programs in the past, and are likely to continue this business posture into the future.

Past programs (B-1 and C-5) have shown that restarting a program is possible, and there was a wide consensus that the B-2 could also be restarted if needed. Although the additional costs of program start-up, learning, supplier qualification, and others need to be factored in to a restart decision, managers of the C-5 and B-1 indicated that an enhanced curtailment program can go far in reducing the time and cost of start up. B-2 already has a plan that entails the storage of government-owned tooling, but an enhanced shut down that also includes purchase of selected contractor tooling and other items should be considered as a more comprehensive insurance policy against the need to restart the B-2.

Finally, another "insurance policy" that should be considered is a modest affordability R&D program for bombers that would be charged with solving the problem of cost growth. This could be performed in close coordination with F-22 and JAST, two fighter programs that are sequentially critically important to sustaining and advancing key technologies and capabilities for complex military aircraft over the mid- and long-term periods.

Summary Of Overall Study Findings

- There is no distinct "bomber industry"
- Cessation of B-2 production will not prevent the nation's aircraft industry from building bombers in the future
- Future bomber production will draw from the broad aerospace capabilities including those supporting other military programs such as F-22 and JAST. Projected growth in the commercial sector will improve the long-term health of suppliers who produce "cross-over" items for military and commercial markets
  - All aircraft primes have designed and/or produced multiple types of military aircraft as well as commercial/business aircraft
  - Aircraft suppliers typically support multiple aircraft programs, both military and commercial
- If required, B-2 can be restarted during the next decade, with the cost and time required depending on a number of variables. Restart capabilities have previously been demonstrated by the restart of the B-1 and C-5 programs. Restart difficulty, time, and cost could be reduced by a low-cost enhancement of the curtailment program
- During any gap in bomber production, capabilities in design and key bomber technologies (including composites and low observables) could be enhanced through a low-level program of R&D -- aimed at cost and risk reductions